GEOIMAGING CHARACTERIZATION
CT SCANNERS

NETL

NATIONAL ENERGY TECHNOLOGY LABORATORY

BACKGROUND

Traditional petrographic and core-evaluation techniques typically aim to determine the mineral make-up and internal structure of rock cores and to analyze the properties influencing fluid flow. Often this type of evaluation is destructive, physically sectioning the core to capture details of the sample's internal composition. The National Energy Technology Laboratory's (NETL) geoimaging facility provides a non-destructive alternative to these traditional methods. The lab hosts three computed tomography (CT) X-ray scanners, an assortment of flow-through instrumentation, and a multi-sensor core logging unit. These technologies work in tandem to provide characteristic geologic and geophysical information at a variety of scales:

- NETL's medical CT scanner and core logger analyze bulk structure, composition, and density variations
- NETL's industrial CT scanner images pore and fracture networks
- NETL's micro-CT scanner allows evaluation of microscopic structure and pore surfaces

Porosity, permeability, fracture roughness and aperture, overall structure, and composition can all be analyzed, yielding quantifiable and relevant parameters, while leaving core samples obtained from the subsurface—which can be difficult or costly to attain—available for further testing.

R&D178, August 2018

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FACILITIES

MEDICAL CT SCANNER

CORE-SCALE CHARACTERIZATION AND FLUID FLOW

The state-of-the-art **Toshiba Aquilion™ RXL medical CT scanner** (Figure 1) is used for bulk core characterization and fluid flow experiments. Although the scanner's resolution (350μm [X] by 350μm [Y] by 500μm [Z]) is the lowest of NETL's three CT scanners, it boasts the fastest scan times. The medical scanner is also adaptable for temperature control, fluid flow, effluent collection, and the application of 3D stresses to the samples. With scan times lasting only seconds, the system can capture, in real time, the migration of fluids and changes in rock material at in situ conditions for petroleum and CO_2 storage reservoirs, thus expanding the knowledge base of fluid mechanics and rock physics at those conditions. Figure 2 illustrates a time series where brine is displacing oil. Figure 3 provides an example of a time series of viscous fingering (top) when liquid CO_2 displaces brine in a sandstone core and the same experiment showing plug flow behavior (bottom) when a surfactant is added to the CO_2.

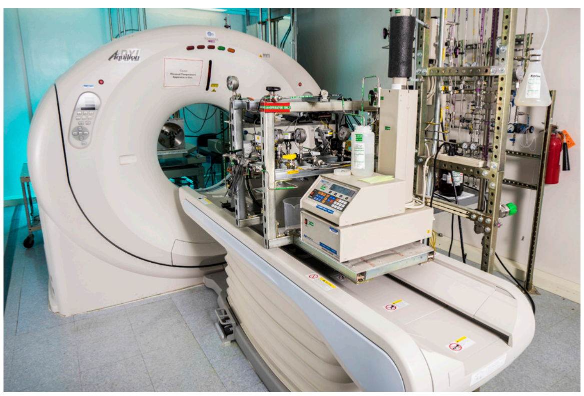

Figure 1. Toshiba Aquilion™ RXL medical CT scanner.

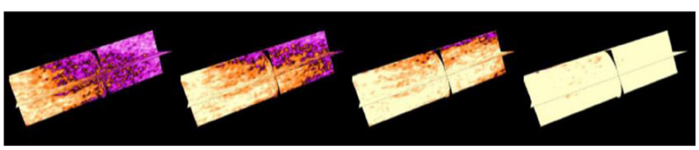

Figure 2. Medical CT scanner imaged multiple stages of an experiment where surfactant laden brine displaced oil in a reservoir rock, with pink indicating oil, and brighter colors indicating saturation with brine.

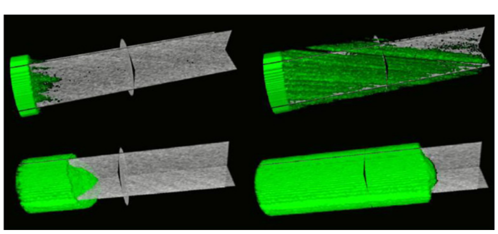

Figure 3. Medical CT scanner images show brine (top) and brine with surfactant (bottom) being displaced by liquid CO_2.

INDUSTRIAL CT SCANNER

PORE-SCALE CHARACTERIZATION AND FLUID FLOW

The **North Star Imaging M-5000 industrial CT scanner** (Figure 4) bridges the gap between NETL's medical and micro-CT scanner machines. The industrial CT scanner allows core-scale characterization in terms of geomaterials' fundamental fluid mechanics and physical properties. Compared to the medical CT scanner, the industrial scanner provides enhanced resolution (5–40μm depending on sample size) but significantly longer scan times (1–2 hours). Smaller samples can be imaged at pore-scale resolution, allowing for the analysis of pore and fracture networks. Core holders allow sample imaging of in situ pressure and temperature conditions. When coupled with the industrial scanner's flow-through capabilities and effluent collection, samples can be imaged prior to, as well as during, a flooding experiment to quantify the physical and chemical changes taking place. Figure 5 highlights a sequence of images showing the changes in fracture aperture after a sequence of pressure cycling. Figure 6 shows the ability of the data processing to identify and highlight different phases within a calcite filled vein (old open fracture).

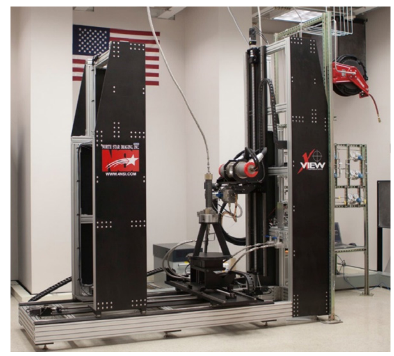

Figure 4. North Star Imaging M-5000 industrial CT scanner.

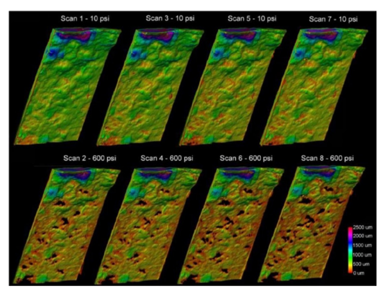

Figure 5. NETL's industrial CT scanner captures the changes in fracture apertures as they fluctuate under cyclic pressure.

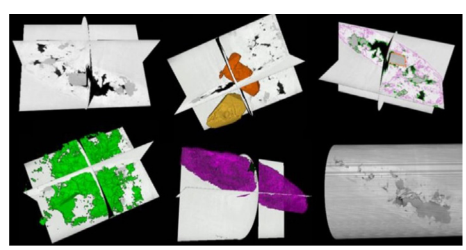

Figure 6. A calcite-filled vein with crystals (yellow and orange) and porous zones (green) is revealed through industrial CT scanner imaging in a shale core from the Martinsburg Formation.

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MICRO-CT SCANNER
SUB-PORE-SCALE CHARACTERIZATION AND FLUID FLOW

The **ZEISS Xradia Micro-CT scanner** (Figure 7) operates at the highest resolution, scanning samples ranging from the size of a piece of thread up to 25mm. This type of resolution at and below the single micron scale has been primarily used to provide detailed data on porosity, structure, and mineral composition on small samples of geomaterials such as sandstone, limestone, volcanic rock, shale, coal, and cement. This unit is also equipped with a beryllium pressure vessel that allows flow experiments to be conducted under in situ reservoir conditions at elevated temperatures and pressures. The trade-off for this high level of detail is the length of time for each scan, which can take days.

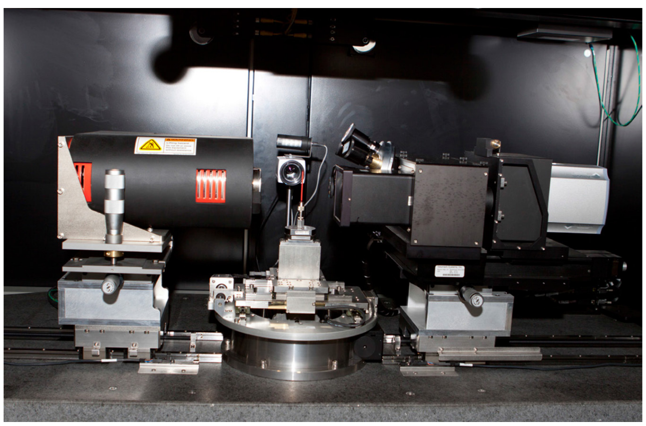

Figure 7. ZEISS Xradia Micro-CT scanner.

Figure 8 shows a reconstructed slice from a piece of scanned sandstone (left) and a 3D volume of the same sample where image processing has allowed for the void space to be isolated and independently visualized and analyzed.

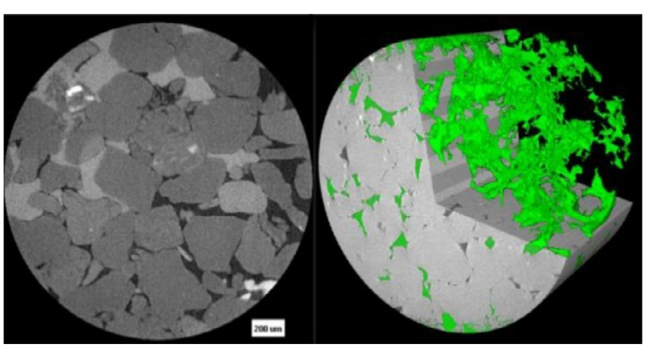

Figure 8. A cross section through a calcite cemented sandstone core (left) and a 3D reconstruction of a sandstone core with connected pore space shown in green (right), generated with the micro-CT scanner.

FLOW-THROUGH CAPABILITIES
LONG-TERM FLUID FLOW

Experiments conducted to examine long-term chemical and morphological changes can last up to many months, but NETL's CT scanners are typically in constant use and down-time is rare. To accommodate long-term fluid flow studies, NETL's geoimaging laboratory hosts additional flow-through equipment, which enables researchers to carry out longer-term experiments without putting a CT scanner out of commission for the duration. In addition, researchers can still image samples before and after the conclusion of the experiment or, if possible, during planned interruptions in fluid flow.

MULTI-SENSOR CORE LOGGER
BULK GEOPHYSICAL PROPERTIES

NETL's multiple-sensor core logging unit (Figure 9) measures bulk physical properties of geomaterials in a fashion comparable to industrial methods, producing data akin to borehole well logs. The NETL logger rapidly obtains high-resolution data including p-wave velocity, gamma-density, natural gamma, resistivity, magnetic susceptibility, and chemical composition using X-ray fluorescence spectrophotometry on whole-round and split core samples. These measurements assist researchers in understanding characteristics of rocks and sediment that are meaningful for geologic, fluid flow, and physical analyses.

Figure 9. Multi-sensor core logging unit.

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Figure 10 provides an example of types of data and the level of detail that can be produced by the mobile core logging system.

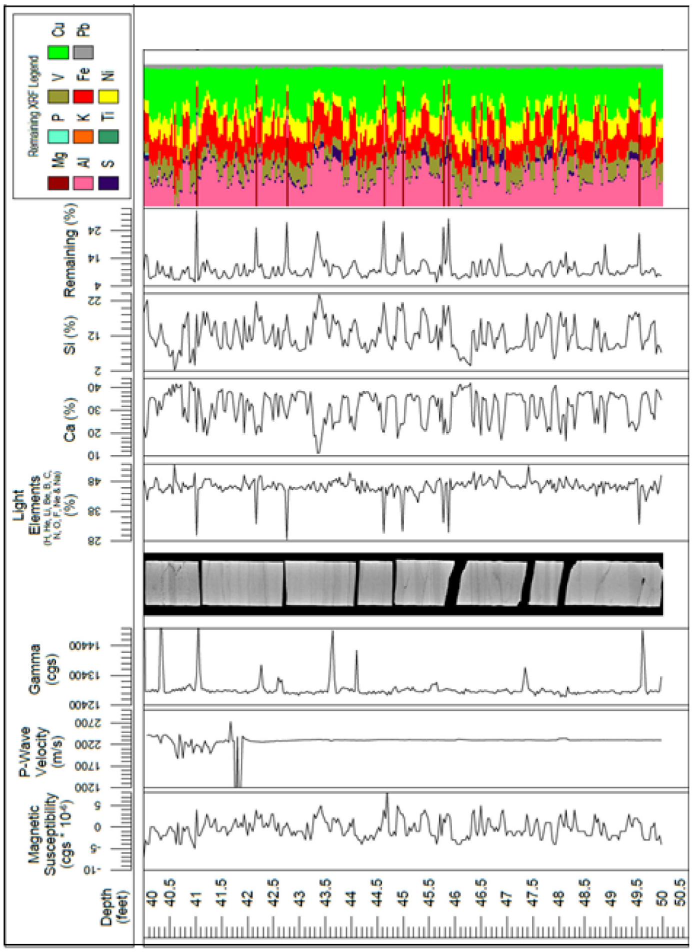

Figure 10. Data obtained with the multi-sensor core logging unit on a fractured Martinsburg Formation shale core.

For more information on evaluating geologic materials at NETL, we invite you to see our Geomaterials Research Facilities Fact Sheet (R&D176). http://www.netl.doe.gov/research/on-site-research/publications/fact-sheets.

PAST AND PRESENT RESEARCH

NETL researchers work with many regional, international, university, and industry partners on projects ranging from carbon storage to improving the safety of deep offshore wells. The following are a few examples:

- Characterization of foamed cements used to seal wells in the oil and gas industry with the goal of improving well safety; this research project was featured on the cover of the January 2015 issue of the Journal of Petroleum Technology
- Evaluation of storage potential in CO_2 target formations in the Ordos Basin of China in partnership with the Chinese Academy of Sciences
- Real-time imaging of CO_2 injection into a brine-saturated reservoir rock
- Observation of dissolution on fracture surfaces due to the interaction with reactive CO_2-saturated brine
- Evaluation of coal interactions with CO_2 at varying pressures

CAPABILITIES AND GOALS

NETL's suite of geoimaging technologies provides researchers with access to comprehensive non-destructive testing and evaluation of a wide variety of geomaterials, including but not limited to sandstones, limestones, carbonates, coals, gas shales, and cements. The facilities enable the experimental examination of complex processes, such as enhanced oil recovery, carbon storage, sealing formation integrity, wellbore safety, geothermal energy production, hydrate formation, and shale gas development. Many of these real-world applications can be examined in the laboratory using actual core samples and fluids from specific target formations at pertinent temperature and pressure conditions, thus allowing researchers to study the changes within both the geologic samples and the fluids they contain.

The resulting data can then be used to improve numerical simulations, leading to more realistic models, economic valuations, and field characterization efforts. Ultimate goals include improving oil recovery techniques, furthering research on carbon storage, addressing safety concerns in the oil and gas industry, reducing oil costs, extending domestic oil supplies, and reducing dependence on foreign oil, while also informing policy makers in the energy field.

Partner

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